SURVIVABILITY OF COLLECTIVE PROTECTION SYSTEMS SUBJECTED TO AIR BLAST LOADS

Jonathan R. Porter
Air Force Research Laboratory, AFRL/MLQF, Suite 2, 139 Barnes Drive, Tyndall AFB, FL 32403
850-283-3073; jon.porter@tyndall.af.mil

John R. Hawk and Michael I. Hammons
Applied Research Associates, Inc., (AFRL/MLQF), Suite 2, 139 Barnes Drive, Tyndall AFB, FL 32403
850-283-3605; mike.hammons@tyndall.af.mil; john.hawk@tyndall.af.mil

ABSTRACT

M28 liners installed in Tent Extendable Modular Personnel (TEMPER) and Small Shelter System (SSS) tents ripped, separated at the zip connections, and failed to maintain pressure when subjected to blast loading by a satchel-sized explosive charge at standoff distances of 100 feet or more, while the parent tents suffered little or no damage at a standoff distance of 65 feet.[1] This paper describes air blast field tests on M28 Collective Protection (CP) System polyethylene liners used in TEMPER and SSS tents, summarizes the experimental results, and outlines the research effort underway to improve survivability of the M28 and similar CP shelter systems.

BACKGROUND

This paper presents the results of air blast tests that were conducted on Tent Extendable Modular Personnel (TEMPER) and Small Shelter System (SSS) personnel tents that were fitted with M28 collective protection system (CPS) liners and outlines the research effort underway to improve survivability of the M28 and similar CP shelter systems. The M28 liner system consists of 16 foot center sections, end sections, and entry vestibules that are joined by airtight zip-type seals (similar to the press seal on a plastic food storage bag, only more robust). TEMPER and SSS tents consist of a fabric material stretched over a metal frame and held in place by metal stakes around the perimeter. Plastic straps with arrowhead type connectors are riveted to the outside of the M28 liner and are attached to the tent frame to hold the liner up when it is not inflated by the ventilation system (Figure 1). A filtered ventilation system supplies toxin free air to the liner and maintains a positive pressure slightly greater than the surrounding atmospheric pressure inside the liner. The positive pressure ensures that the flow of air though small holes or loose seals is outward from the M28 liner, preventing flow of contaminated air into the protective system. This allows personnel inside the shelter to work, eat or rest without the burden of individual protective equipment. This advantage is nullified if the liner has a breach so large that the ventilation system is unable to maintain positive pressure and outward air flow, as through a large tear or complete failure of a zip seal.

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Figure 1. Clockwise from top, right: typical TEMPER tent[1]; M28 CPS liner and detail of plastic arrowhead straps riveted to the liner and used to anchor the liner to the tent frame[2]; zip-type seal that joins liner sections[2].

An air blast creates a compression wave that moves outward in all directions, similar to the wave created by a person clapping his hands together except that the compression wave from an air blast initially moves faster than the speed of sound in air. The pressure disturbance is propagated over long distances without significant displacement of individual air molecules. As the compression wave from an air blast propagates outward in all directions it weakens as it spreads over a larger area. The incident pressure on an object in the path of the compression wave is a function of the distance, commonly called *standoff distance*, of the object from the source of the explosion. The pressure of the freely propagating compression wave is called *incident pressure*. When the wave encounters a surface in its path some of the wave is reflected, the amount of reflection being a function of the rigidity of the reflecting surface and orientation of the surface to the wave. *Reflected pressure* develops near the reflecting surface and is always greater in magnitude than the surrounding incident pressure. *Impulse* is a measure of the pressure and duration through which the pressure persists, and it is found by calculating the area under the pressure-time history curve measured at a specific distance from the source of an explosion.

In these experiments the CPS liners failed at distances and incident pressures at which the parent tents suffered little or no damage. Charge weights required to produce the relatively low pressure that could cause failure of the M28 liner are within the capability of even an unsophisticated aggressor. The goal of this project is to identify methods that could be easily retrofitted in present CP shelter systems to bring survivability of the liners to a level equal to that of the parent tents and to identify mitigation techniques that could be incorporated into future shelter designs to make them inherently more blast resistant.

TEST DESCRIPTION

The Air Force Research Laboratory (AFRL) at Tyndall AFB conducted tests during December 1999 and January 2000, and the USAF Force Protection Battlelab conducted tests during March through June 2001. TEMPER and SSS tents with and without CPS liners installed were exposed to hemispherical surface air blasts. Various weights of explosives and standoff distances were used to achieve a range of pressures at the test specimens. Incident and reflected pressures, and pressure impulses were measured at the tents. A representative test layout is shown in Figure 2.

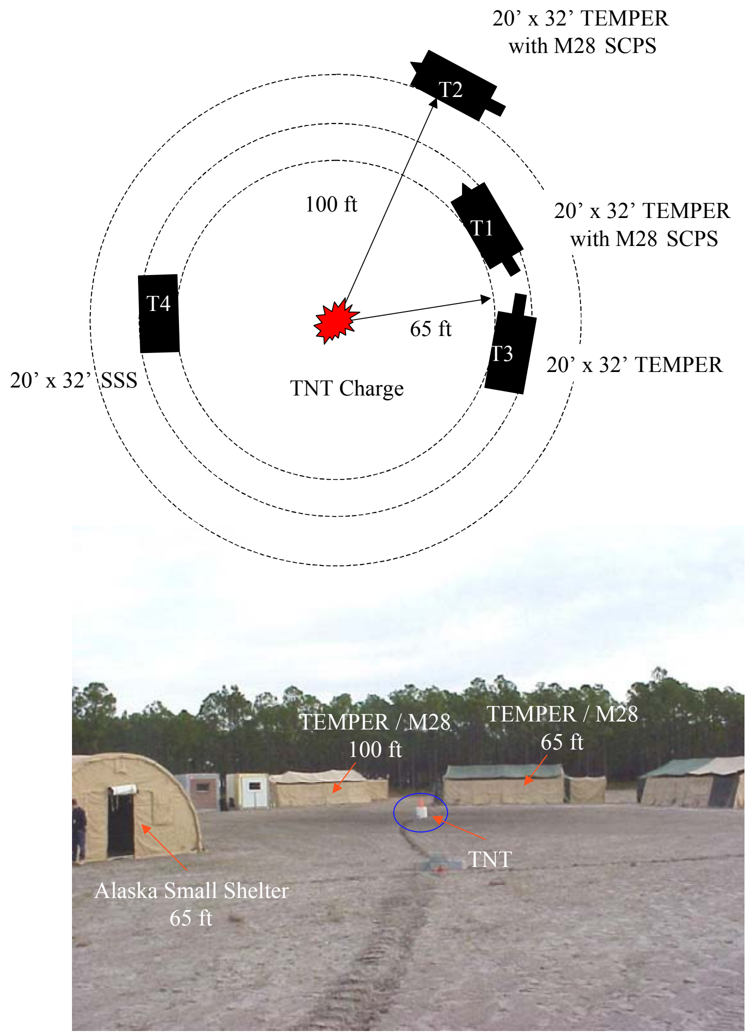

Figure 2. Overhead view of a typical test layout is shown with an accompanying photograph that shows the test articles and placement of the explosive.[1]

TEST RESULTS

Tests revealed that complete failure of the CPS liners generally occurred at blast impulses of 20 psi-msec. Complete failure of the liners was characterized by tears in the liner and failure of zip seals over an area large enough to allow flow of air out of the liner at a rate greater than the filtered ventilation system could supply, causing complete loss of positive pressure inside the liner. Most tears in the CPS liners happened near areas where the plastic straps that are used to anchor the liner to the tent frame are joined to the liner. These fastener straps are attached to the liner by passing a rivet through the strap and through two thin plastic discs on both the inside and outside of the liner to reinforce the area around the rivet. Interestingly, the zip seals failed most often on the side of the tent facing away from the source of the blast. Photographs of typical failures that were observed appear in Figure 3.

In comparison, fabric and metal frame shelters withstood relatively high blast pressures and impulses. Damage to the tents generally took the form of deformation of the metal frame. The fabric transferred the blast load efficiently to the frame and generally suffered little damage even at the point of complete failure of the frame. Minor damage to the tents, characterized by bending of frame members up to two inches and/or small tears in the fabric, occurred at blast impulses above 15 psi-msec. Severe damage, characterized by frame deformation of two to six inches, occurred at impulses of 35 psi-msec,

and even with severe damage the tent frames adequately supported the shelters and could be reoccupied after a few adjustments to the hold-down stakes and realignment of frame members. Complete failure of tent frames was observed to occur near 50 psi-msec, though the tent fabric often survived with few tears even when the metal frame collapsed.

Figure 3. CPS liner failures. Clockwise from top, left: TEMPER tent with CPS liner lying outside the bottom of the tent[2]; two photographs of tears in liners[2, 1]; failed zip seals[2].

Data from tests on TEMPER and SSS tents was used to create the graph shown in Figure 4, which illustrates the level of damage caused by different combinations of pressure and impulse from air blasts. The figure also shows the range of pressures and impulses at which failures of M28 CPS liners have been observed. This depiction highlights a significant shortcoming of the M28 CPS liner; the survivability of the liner to air blast is not well balanced with the survivability of the parent tent. Improving the resistance to damage from air blast of CPS liners would make the entire integrated structure a more effective CP system.

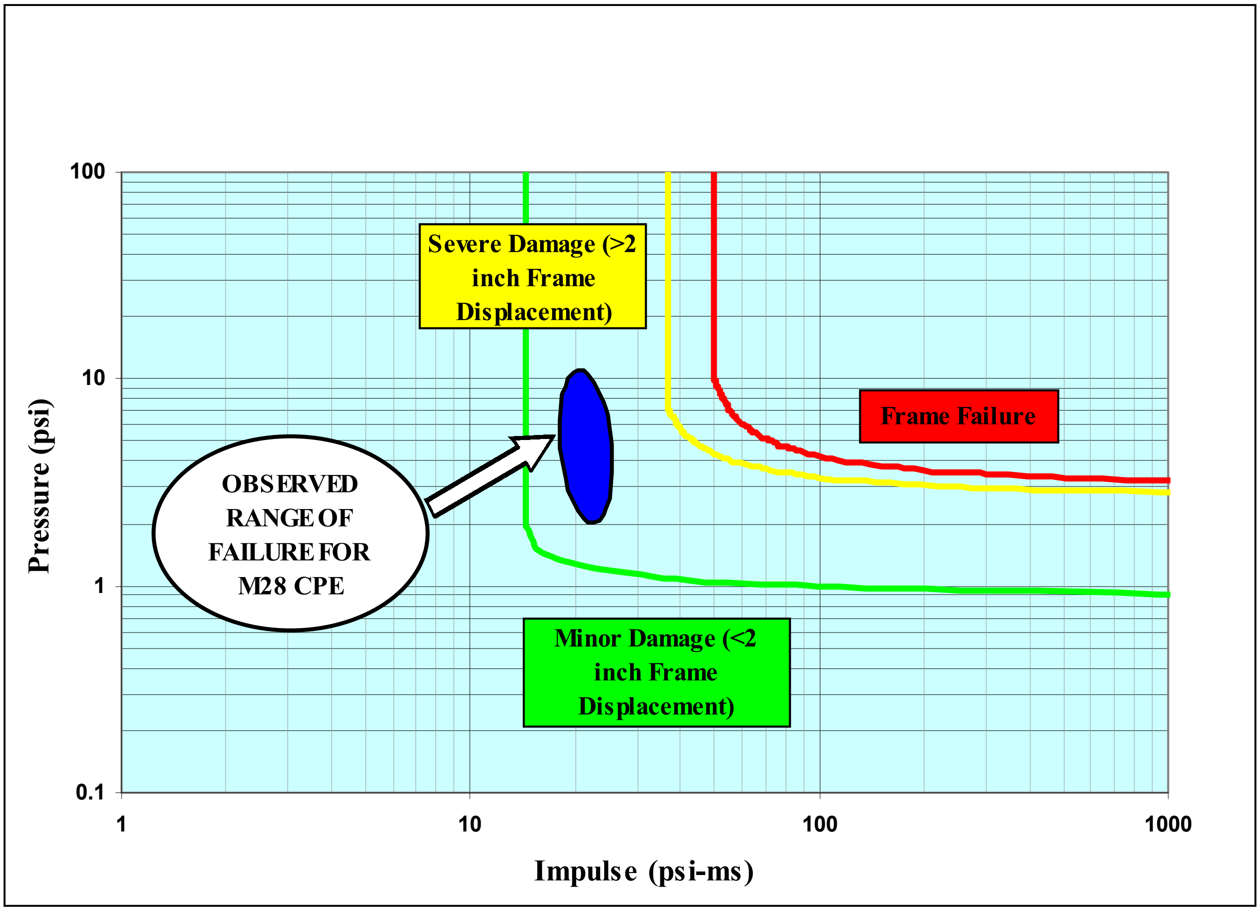

Figure 4. Pressure-impulse response curves for tents.[2]

CONCLUSIONS

The compression wave created by the air blast is a three-dimensional phenomenon; i.e., the overpressure surrounds the entire outside of the tent-CPS liner system. The pressure load on the tent itself is transferred to the metal frame members, which are capable of withstanding significant load. The CPS liner acts much like an air filled bladder: the surrounding pressure pushes in on the liner and compresses the air into a smaller volume until the pressure inside equals the pressure outside. However, the plastic arrowhead straps that anchor the liner to the frame constrain the motion of the liner, and because the anchor points are reinforced and stronger than the rest of the liner material, the liner tears under the load. It might seem an easy fix to simply do away with the straps or replace them with shock cord so the liner is free to deflect under blast pressure; however, light fixtures, cables, and other items are intended to be hung from the inside

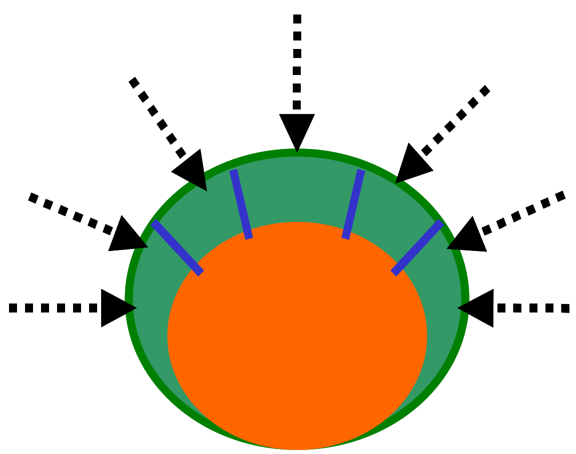

Figure 5. CPS liner compresses (green to orange) under the surrounding pressure load. Support straps (blue) constrain the liner where they are attached and cause high localized stress and tearing.

roof of the liner by nylon ties, and the anchor straps help support the weight of these items. The slight positive pressure inside the liner is insufficient to support the liner when these additional loads are attached, and without the support straps the CPS liner would sag considerably.

The research proposed in this effort will investigate the cause of material failures at anchor points and the cause of seal separation of CPS liners when subjected to air blast loading. Materials characterization testing and analytical modeling will be done to predict blast response of pressurized CPS liner components used in the Tent Extendable Modular Personnel (TEMPER), the Small Shelter System (SSS), the Modular General Purpose Tent Systems (MGPTS), and the Chemical-Biological Protection System (CBPS). Performance requirements (e.g., tensile/shear strength) of the materials and closures will be identified, and possible modifications (retrofits) to existing and emerging CP systems will be proposed. Blast mitigation improvements will be developed and field tested to validate the predictive model and proposed design improvements. This effort will be used to provide design guidance to improve current CP systems and provide vital information for consideration in the designs of JTCOPS Block 2 and other CP shelters being considered for future development.

ACKNOWLEDGEMENTS

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